

ON THE PHYSICAL ACTION OF THE MICROPHONE<sup>1</sup>

IN the paper read on May 9 before the Royal Society I gave a general outline of the discoveries I had made, the materials used, and the forms of microphone employed in demonstrating important points. I have made a great number of microphones each for some special purpose, varying in form, mechanical arrangement, and materials. It would require too much time to describe even a few of them, and as I am anxious in this paper to confine myself to general considerations, I will take it for granted that some of the forms of instrument and the results produced are already known.

The problem which the microphone resolves is this—to introduce into an electrical circuit an electrical resistance, which resistance shall vary in exact accord with sonorous vibrations so as to produce an undulatory current of electricity from a constant source, whose wave-length, height, and form shall be an exact representation of the sonorous waves. In the microphone we have an electric conducting material susceptible of being influenced by sonorous vibrations, and thus we have the first step of the problem.

The second step is one of the highest importance: it is essential that the electrical current flowing be thrown into waves of determinate form by the sole action of the sonorous vibrations. I resolved this by the discovery that when an electric conducting matter is in a divided state, either in the form of powder, filings, or surfaces, and is put under a certain slight pressure, far less than that which would produce cohesion and more than would allow it to be separated by sonorous vibrations, the following state of things occurred:—The molecules at these surfaces being in a comparatively free state, although electrically joined, do of themselves so arrange their form, their number in contact, or their pressure (by increased size or orbit of revolution), that the increase and decrease of electrical resistance of the circuit is altered in a very remarkable manner, so much so as to be almost fabulous.

The problem being resolved it is only necessary to observe certain general considerations to produce an endless variety of microphones each having a special range of resistance.

The tramp of a fly or the cry of an insect requires little range, but great sensitiveness, and two surfaces therefore of chosen materials under a very slight pressure, such as the mere weight of a small superposed conductor, suffice; but it would be unsuitable for a man's voice, as the vibrations would be too powerful, and would, in fact, go so far beyond the legitimate range, that interruptions of contact amounting to the well-known "make and break" would be produced.

A man's voice requires four surfaces of pine charcoal, as is described in my paper to the Royal Society, six of willow charcoal, eight of boxwood, and ten of gas carbon. The effects are, however, far superior with the four of pine than with either the ten of gas carbon or any other material as yet used. It should be noted that pine wood is the best resonant material we possess; and it preserves its structure and quality when converted into the peculiar charcoal I have discovered and described.

It is not only necessary to vary the number of surfaces and materials in accordance with the range and power of the vibrations, but these surfaces and materials must be put under more or less pressure in accordance with the force of the sonorous vibrations. Thus, for a man's voice the surfaces must be under a far greater pressure than for the movements of insects; still the range of useful effect is very great, as the boxes which I have specially arranged for a man's voice are still sensitive to the tick of a watch.

In all cases it should be so arranged that a perfect undulatory current is obtained from the sonorous vibrations of a certain range. Thus, when speaking to a microphone transmitter of human speech, a galvanometer should be placed in the circuit, and, while speaking, the needle should not be deflected, as the waves of + and - electricity are equal, and are too rapid to disturb the needle, which can only indicate a general weakening or strengthening of the current. If the pressure on the materials is not sufficient, we shall have a constant succession of interruptions of contact, and the galvanometer-needle will indicate the fact. If the pressure on the materials is gradually increased, the tones will be loud but wanting in distinctness, the galvanometer indicating interruptions; as the pressure is still

increased, the tone becomes clearer, and the galvanometer will be stationary when a maximum of loudness and clearness is attained. If the pressure be further increased, the sounds become weaker, though very clear, and, as the pressure is still further augmented, the sounds die out (as if the speaker was talking and walking away at the same time) until a point is arrived at where there is complete silence.

When the microphone is fixed to a resonant board the lower contact should be fixed to this board, so that the sonorous vibrations act directly on it. The upper contact, where the pressure is applied, should be as free as possible from the influence of the vibrations, except those directly transmitted to it by the surfaces underneath; it (the upper surface) should have its inertia supplemented by that of a balanced weight. This inertia I find necessary to keep the contact unbroken by powerful vibrations. No spring can supply the required inertia, but an adjustable spring may be used to ensure that the comparatively heavy lever shall duly press on the contacts.

The superposed surfaces in contact may be screwed down by an insulated screw passing through them all, thus doing away with the lever and spring; but this arrangement is far more difficult to adjust, and the expansion by heat of the screw causes a varying pressure. It is exceedingly simple, however, easily made, and illustrates the theoretical conditions better than the balanced lever I have adopted in practice. In order to study the theoretical considerations, and that with the most simple form of microphone, freed from all surrounding mechanisms, let us take a flat piece of charcoal two millims. thick and one centim. square, and, after making electrical contact by means of a copper wire on the lower surface, glue that to a small resonant board, or, better for the purpose of observation, to a block or cube of wood ten centims. square. Upon this superpose one or more similar blocks, the upper surface in communication with a wire, the lower resting *flat*, or as nearly so as possible, on the lower block.

The required pressure is put on the upper block, and while in this state the two may be fastened together with glue at the sides, or, better, by an insulated screw. The pressure can then be removed, as the screw or glue equally preserves the force. Let the lower piece be called A and the upper B: when we put this block or board under sonorous vibrations, we cannot suppose an undulatory movement of the actual wave-length in such a mass, that is a length comparable with the real wave-length of the sonorous wave which may be several feet. Now we cannot suppose a wave of any length without admitting that the force must be transmitted from molecule to molecule throughout the entire length: thus any portion of a wave, of which this block represents a fraction, must be in molecular activity. The lower portion of the charcoal A, being part of the block itself, has this molecular action throughout, transmitting it also to the upper block. How is it that the molecular action at the surfaces A and B should so vary the conductivity or electrical resistance as to throw it into waves in the exact form of the sonorous vibrations? It cannot be because it throws up the upper portion, making an intermittent current, because the upper portion is fastened to the lower, and the galvanometer does not indicate any interruption of current whatever. It cannot be because the molecules arrange themselves in stratified lines, becoming more or less conductive, as then surfaces would not be required—that is, we should not require discontinuity between the blocks A and B; nor would the upper surface be thrown up if the pressure be removed, as sand is on a vibrating glass. The throwing up of this upper piece B when pressure is removed proves that a blow, pressure, or upheaval of the lower portion takes place—that this takes place there cannot be any doubt, as the surface, considered alone (having no depth), could not bodily quit its mass. In fact, there must have been a movement to a certain depth; and I am inclined to believe, from numerous experiments, that the whole block increases and diminishes in size at all points, in the centre as well as the surface, exactly in accordance with the form of the sonorous wave. Confining our attention, however, to the points A and B, how can this increased molecular size or form produce a change in the electrical waves? This may happen in two ways: *first*, by increased pressure on the upper surface, due to its enlargement; or, *second*, the molecules themselves, finding a certain resistance opposed to their upward movement, spread themselves, making innumerable fresh points of contact. Thus, an undulatory current would appear to be produced by infinite change in the number of fresh contacts. I am inclined to believe

<sup>1</sup> By Prof. Hughes. Communicated to the Physical Society, June 8, 1878.

that both actions occur, but the latter seems to me the true explanation; for if the first was alone true, we should have a far greater effect from metal powder, carbon, or some elastic conductor as metallised silk, than from gold or other hard unoxidisable matter; but as the best results as regards the human voice were obtained from two surfaces of solid gold, I am inclined to view with more favour the idea that an infinite change of fresh contacts brought into play by the molecular pressure affords the true explanation. It has the advantage of being supported by the numerous forms of microphone I have constructed, in all of which I can fully trace this effect.

I have been very much struck by the great mechanical force exerted by this uprising of the molecules under sonorous vibrations. With vibrations from a musical box two feet in length I found that one ounce of lead was not sufficient on a surface of contact one centim. square to maintain constant contact; and it was only by removing the musical box to a distance of several feet that I was enabled to preserve continuity of current with a moderate pressure. I have spoken to forty microphones at once, and they all seemed to respond with equal force. Of course there must be a loss of energy in the conversion of molecular vibrations into electrical waves, but it is so small that I have never been able to measure it with the simple appliances at my disposal. I have examined every portion of my room—wood, stone, metal, in fact all parts, and even a piece of India-rubber—all were in molecular movement whenever I spoke. As yet I have found no such insulator for sound as gutta-percha is for electricity. Casoutchouc seems the best; but I have never been able, by the use of any amount at my disposal, to prevent the microphone reporting all it heard.

The question of insulation has now become one of necessity, as the microphone has opened to us a world of sounds, of the existence of which we were unaware. If we can insulate the instrument so as to direct its powers on any single object, as at present I am able to do on a moving fly, it will be possible to investigate that object undisturbed by the pandemonium of sounds which at present the microphone reveals where we thought complete silence prevailed.

I have recently made the following curious observation:—A microphone on a resonant board is placed in a battery-circuit together with two telephones. When one of these is placed on the resonant board a continuous sound will emanate from the other. The sound is started by the vibration which is imparted to the board when the telephone is placed on it; this impulse, passing through the microphone, sets both telephone-disks in motion; and the instrument on the board, reacting through the microphone, causes a continuous sound to be produced, which is permanent so long as the independent current of electricity is maintained through the microphone. It follows that the question of providing a *relay* for the human voice in telephony is thus solved.

The transmission of sound through the microphone is perfectly duplex, for if two correspondents use microphones as transmitters and telephones as receivers, each can hear the other, but his own speech is inaudible; and if each sing a different note no chord is heard. The experiments on the deaf have proved that they can be made to hear the tick of a watch, but not, as yet, human speech distinctly; and my results in this direction point to the conclusion that we only hear ourselves speak through the bones and not through the ears.

However simple the microphone may appear at first glance, it has taken me many months of unremitting labour and study to bring to its present state through the numerous forms each suitable for a special object. The field of usefulness for it widens every day. Sir Henry Thompson has succeeded in applying it to surgical operations of great delicacy, and by its means splinters, bullets, in fact all foreign matter, can be at once detected. Dr. Richardson and myself have been experimenting in lung- and heart-diseases, and although the application by Sir H. Thompson is more successful, I do not doubt but that we shall ultimately succeed. There is also hope that deafness may be relieved, for telephony articulation has become perfect and the loudness increased. Duplex and multiplex telegraphy will profit by its use, and there is hardly a science where vibrations have any direct or indirect relation which will not be benefited. And I feel happy in being able to present this paper on the results obtained by a purely physical action to such an appropriate and appreciative body as the Physical Society.

In conclusion, allow me to state that throughout the whole of my investigations I have used Prof. Bell's wonderfully sen-

sitive telephone instrument as a receiver, and that it is thanks to the discovery of so admirable an appliance, that I have been enabled to commence and follow up my researches in microphony.

### LABORATORY NOTES

**DURING** the daily routine of life in a laboratory many observations are made of an isolated character, perhaps having no direct bearing on the subject in hand, but which, nevertheless, may be eminently suggestive to other minds. The record of such observations are often lost; they are not communicated unless they find a place in a larger research, and they go to form the capital which every worker is accumulating till his death, much of which, unfortunately, perishes with him. I therefore cordially approve of the suggestion of the Editor that workers in the various departments of experimental science should occasionally write a few notes containing a brief account of any observations recently made, and I shall be glad to contribute my quota.

1. *Carl Zeiss' New Oil Immersion Lens.*—This is a  $\frac{1}{4}$ th-objective, on the immersion system, in which the fluid used is oil of cedar-wood. For amount of light, clearness of definition, resolving power, and flatness of field, it is superior to any lens I have worked with. For use in histological observation, it does not require any special arrangement of light. In examining such objects as blood-corpuscles or salivary cells with very high powers it is of great advantage to be able to use cover-glasses of ordinary thickness, and to have a serviceably-working distance. This is secured by Zeiss' lens. I have found that, with ordinary Nos. 6 and 7 Hartnack-objectives, more light is obtained by using them as immersion-lenses with a drop of equal parts of oil of cedar-wood and olive oil. The method of using fluids of high refractive index, on the immersion principle, seems to me likely to lead to valuable results. With oblique light, cutting off light from the mirror, the performance of Zeiss' lens is remarkably good.

2. *The Phonograph as a Transmitter.*—By placing Hughes' microphone on the disc of the phonograph the latter will transmit the sounds recorded on the tinfoil to a telephone at a distance. Thus we have a combination of microphone, phonograph, and telephone, which promises to be of use. It is very suggestive to hear the phonograph speaking in one room and to know that some one else in another room, or at a long distance off, is also hearing a repetition of the sound. I have no doubt that arrangements might be made by which the sound might be reproduced in a dozen different places at once.

3. *The Working of the Phonograph.*—After a good deal of experience I have come to the conclusion that a thin and slightly elastic membrane is the most suitable for loudness, whilst a rigid non-elastic membrane is most adapted for distinctness. From a consideration of the histological structure of the drum of the ear this is what one would expect. After the impressions have been made on the tinfoil, distinct speech, in a feeble voice, of most peculiar quality, like what one would imagine to be the tones of the fairies of old, can be heard from one of Marey's tambours, by bringing the point of the lever on the surface of the phonographic cylinder. With this method there is almost no friction, and consequently the marks on the tin-foil are not quickly rubbed out. By connecting a tube with the tambour and carrying it from the tambour to the ear, sounds may be heard, even as speech, after the marks have been so erased from the tinfoil as to be scarcely perceptible to the eye. Thus the tambour, when so used, may be said to be a microphone.

4. *The Microphone.*—I have tried many experiments with the ingenious arrangement of Mr. Hughes, and have been much impressed with its extreme sensitiveness. It may be used to make and break at pleasure the primary coil of the induction machine. When fixed to the box of a monochord the slightest touch of the wire with a camel-hair pencil sounds loudly in the distant telephone. When placed on the sounding-board of a piano, I have heard distinctly a complicated piece of music eighty yards away; when attached to the throat by an india-rubber band, the faintest trill or whisper is audible; and it transmits the muscular sound from a powerful biceps.

5. *A Lecture Experiment.*—Place the heart of a frog on the electrodes of Du Bois-Reymond in connection with a sensitive reflecting galvanometer. The rhythm of the pulsations may then be observed by the swinging to and fro of the spot of light on a transparent screen. This has often been observed by